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Levels and properties of map perception

Abstract. Map perception consists of numerous processes of information processing, taking place almost simultaneously at different levels and stages which makes it conditioned by many factors. In the article, a review of processes related to the perception of a map as well as levels and properties of perception which impact its course and the nature of information obtained from a map is presented. The most important process constituting the basis of a map perception is a visual search (eye movement). However, as stated based on the studies, the process is individual depending on the purpose of map perception and it may be guided by its image (visual search guidance) or by the knowledge of users (cognitive search guidance). Perception can take place according to various schemes – "local-to-global" or "global-to-local", or in accordance with the guided search theory. Perception is divided into three processes: perceiving, distinguishing and identifying, which constitute the basis to interpret and understand a map. They are related to various degrees of intellectual involvement of the user and to various levels of questions concerning the relations between signs and their content. Identification involves referring a sign to its explanation in the legend. Interpretation means transformation of the initial information collected from the map into derivative information in which two basic types of understanding take place: deductive and inductive. Identification of geographical space objects on the map and the interpretation of its content constitute the basis to introduce information into memory structures. In the brain a resource of information is generated called geographic knowledge or spatial representation (mental map) which may have a double nature – verbal or pictorial. An important feature of mental maps is organization of spatial information into hierarchical structures, e.g. grouping towns into regions as well as deformation of spatial relations between individual elements and their groups independent of consciousness.

The process of map perception depends on various factors, including the nature, scale and map content, the degree of its complexity and compliance of the map language with cartographic principles. Important factors also include cartographic competencies of the recipient of a map conditioned by age, education and the task type. It is related to types of information about geographical space: semantic – concerning spatial references of particular objects and structural – connected to relations between elements of a map. Such relations may be determined at the regional or global level, they may concern qualitative or quantitative features as well as changes in time.

Nowadays, an important factor impacting the nature and consequences of map perception is the situation in which the process occurs. Traditionally, static and unchanging maps are used under other conditions than computer maps and navigation systems, making it possible to freely zoom in and zoom out the image and its spatial scope as well as to quickly go from one image to another.

Today, when the predominant way of map use is their perception on the screens of navigation systems, processes of map perception and factors conditioning it are also significant to understand the process. In the analysis of map perception, also tasks which are implemented using the map and the nature of information obtained by the map user must be taken into account.

Keywords: map perception, map use, map interpretation, mental maps, cartographic information

1. Introduction

Impressions as a result of map perception and information collected on its basis, constitute consequences of numerous processes of information processing occurring almost simultaneously at various levels or stages – from map perception by the visual system, to under-

standing of its content and making decisions. Complexity and numerous levels of this process result in the fact that it is conditioned by numerous factors, such as the nature of a given map, the situation in which map perception occurs and the carrier on which it is saved as well as characteristics of the map recipient. Maps are used in various ways depending on the purpose and tasks we implement using them, searching for answers to various questions. Such tasks can be implemented at various levels of map perception. The recipient applies different mental operations, obtaining information referring to the location of objects, their attributes and spatial situation. In this article, I present processes which constitute map perception, their fundamental properties and factors impacting their course. Most studies on map perception conducted at the end of the 20th century concerned printed maps, however there is no doubt that basic dependencies presented in this article occurring between levels of perception and factors impacting its course as well as the nature of information obtained from a map also refer to new forms and carriers of maps as well as situations when they are used.

2. Stages of map perception

In the process of visual perception psychologists distinguish two fundamental stages: initial, in which shapes and objects are distinguished from the visual stage, and later, in which shapes and objects are recognized (J.R. Anderson 1995). At the first stage, the main role is played by factors related to properties of the visual system. Referring to map perception, they were presented in the article on features of a cartographic image in map perception (W. Żyszkowska 2016b). The second stage of perception is related to participation of higher level brain structures, including most of all attention and memory. However, regardless of the level at which map perception takes place, its basis is always the visual search process[1], which constitutes the first stage of perception or is a connector between the first and second stage.

2.1. Visual search

The limited range of the field of vision of the eye when looking at a map requires constant transfer of sight across its surface. When the eyes stop searching, the lens of the eye focuses on the fixation point and the eye receives information from the field covered by the macula, which is then transferred to the visual field of association, and then the eyes are directed towards a different point. Information collected from the map during a short time of looking is collected in iconic memory, from where – if attention is not engaged – they disappear.

Studies on visual search in the context of map perception were conducted mainly in the 70s and 80s of the previous century (A.M. MacEachren 1995, D.R. Montello 2002, W. Żyszkowska 2015). They indicated that the system of eye movements has an individual nature, and fixation points and time of their duration are generally related to the areas containing more information. The fixation system depends on whether map perception occurs as a free scan or it is directed towards a certain task and on the type of task. M.W. Dobson (1985) established that in such a case a visual search can be visually guided (visual search guidance – VSG), and then it is strictly related to attention, or it can be cognitively guided (cognitive search guidance – CSG), during which long-term memory is engaged.

When the recipient is looking at a map without a clear purpose, without a determined task and without engaged attention, the eye registers only general features of the special layout of the map pattern and the most eye-catching signs. At this stage, the recipient may not associate the features of the image with memory resources. While, in the task-oriented situation, the process of map perception is guided by attention, aimed at task implementation and the fixation system is affected by the type of task, and therefore cognitive expectations and instructions. The user's experience plays here an important role (G.F. Jenks 1973; A.A. De Lucia 1976; H.W. Castner and D.W. Lywood 1978; H.A. Sanford 1980; M.W. Dobson 1977, 1979, 1985).

[1] Such a term was used by M.W. Dobson (1985) and A.M. MacEachren (1995). A. Ciołkosz-Styk (2011) determined it as "visual search", and X. Li, A. Çöltekin and M.J. Kraak (2010) as well as A. Çöltekin, S. Fabrikant and M. Lacayo (2010) use a term of "eye movement".

For several years, the process of visual search has been a subject of scientific interest (X. Li, A. Çöltekin and M.J. Kraak 2010; A. Çöltekin, S.I. Fabrikant and M. Lacayo 2010; T. Opach 2011)[2]. Studies confirm statements that each user applies their own individual strategy to carry out a visual search and that the fixation course is affected by the nature of the map image.

2.2. Perception schemes

The order and functions of perception stages in visual information processing constitute a subject of two groups of theories adopting opposing assumptions (M. Materska and T. Tyszka 1997). Theories from the first group assume that the perception process takes place according to the down-up or local-to-global scheme, and therefore it commences from the local stage and is guided by information from the image. Recognition of the image is guided by sensory information. At the first stage of perception, an image is divided into elementary visual impressions (down) which at the second stage are transformed into sets of features and confronted with the possessed knowledge (up). In the case of map perception, it should be assumed that particular elements of signs are seen first, and then information about groups and spatial systems is built from it (L. Ratajski 1978, C.G. Head 1984 and A. Czerny 1994). Such a scheme is typical for a visually guided search.

According to the second scheme up-down or global-to-local it is assumed that the initial stage has a general nature and it is guided by information saved in memory, and therefore guided cognitively. During the first short stage, simultaneous (parallel) identification of fundamental features of the entire field of sight takes place. The second longer stage involves subsequent (serial) perception of features and their analysis, and then their potential secondary association into a general complex representation of an object. This group of theories is related to one of the most well-known theories called Gestalt psychology. Gestalt theory followers believe that interpretation of an image is fundamentally affected by its entire form and what creates a form, and the relation of the background to the figure, which occurs in it, is especially important (R. Arnheim 1976). In the case of map perception, the recipient notices the map as a whole first and register the general layout of signs. Principles of semiology of graphics by J. Bertin (1967) and the term *graphique*, which in his opinion is the only form allowing understanding and acquisition of the map content and which at a single glance transfers information about the most significant features of spatial relations occurring on the area presented on the map are based on this assumption.

From the perspective of cartography, the guided search theory, combining both approaches, suggested by J.M. Wolf seems to be particularly interesting (K.R. Cave and J.M. Wolf 1990). During the general stage, the sight system creates a scheme, i.e. an “activation map” which is conditioned by the power of contrast on the image and similarity to the searched purposes in the short-term memory. The decision whether the noticed element of the content is compliant with the purpose is made during the detailed stage when fixation on particular elements occurs. Therefore, in visual information processing, both schemes, i.e. up-down and down-up processing function simultaneously (K.R. Cave and J.M. Wolf 1990).

During map perception, general perception may dominate over detailed perception, especially in the case of maps containing one graphical variable. Therefore, the principles of semiology of graphics suggested by J. Bertin (1967) are used for such organization of information on the map that the general stage always fulfills the fundamental role in map perception[3]. However, if the spatial system on the map is complex, consisting of numerous elements or elements with a high degree of detail, perception will have a detailed nature and the general stage will be nearly completely excluded from consciousness.

2.3. Processes related to map perception

J.S. Keates (1982) and L. Ratajski (1989) differentiated three processes of a various na-

[2] Currently, such studies are conducted within the so-called eye tracking (T. Opach 2011).

[3] J. Bertin (1967) was an opponent of reading maps and he reluctantly admitted that it is sometimes applied by recipients of maps.

ture in map perception, which can be treated as levels of map perception: Perceiving, distinguishing[4] and identifying (recognition); they constitute a basis to interpret and understand a map. They result in knowledge about geographical space, i.e. spatial representations created in the recipient's brain.

Analyzing the levels of map perception, A.H. Robinson and B.B. Petchenik (1976) paid attention to the degree of intellectual involvement of the user. At the first stage, the viewer may look at the map without understanding its content. At the second level, the recipient undertakes action similar to reading a map, and at the highest level and analysis of the content and map interpretation takes place. Also J.M. Olson (1976) associated the levels of map perception with tasks of an increasing degree of intellectual involvement; however, she characterized them differently. The three levels distinguished by her correspond to levels of questions formulated by J. Bertin (1967) which concern the relation between signs and their content. At the first level – differential-associative – individual features of symbols are compared and relations between symbols and their meaning are established. At the second level – ordinal – properties of groups of symbols on the map as a whole are recognized: spatial system, similarity of systems known from other maps, and therefore relations between groups of symbols. At the third level – scaling – differences between signs are assessed based on their comparison with the map legend. Scaling may occur on the interval or ratio scale. The highest level is the identification level when a place or a value is found, the type of distribution is noticed or a group hierarchy, etc.

2.3.1. Identification of signs

Identification must be understood as judgment relation implementation (L. Ratajski 1971), which involves association of a noticed sign on the map with its marking or a class of objects most often by referring to the explanation of the sign in the legend. Frequently, for this purpose the object name is used. The object must be noticed by the recipient as a "figure" on the background of other elements of the map. If the map presents known content, referring to the legend is not necessary as identification occurs through referring to knowledge stored in long-term memory. Identification may occur only with engaged attention as it is related to awareness and understanding. If knowledge stored in the memory is compliant with the information obtained from the map and the hypothesis is probable, image recognition takes place.

Identification of known surface and linear objects involves recognition of the typical elements of the shape of such objects. However, if we are dealing not with "figures" on the "background", but with configuration of parallel surfaces of which none plays the role of the figure or the background, identification of the spatial system involves determination of the topological relations, most of all of the neighborhood type. At the moment of identification of an object, recognition of its meaning takes place not only in the sense of marking, but also in the sense of geographical meaning.

Identification constitutes a transition stage between perception of a sign and its interpretation and it is strictly related to differentiation in which also experience and knowledge participate. An experienced map user can perceive less clear differences than an inexperienced user, and this skill can be practiced through working with a map.

2.3.2. Interpretation

Interpretation involves transformation of the initial information obtained from the map into derivative information, i.e. creating and verifying preliminary hypotheses concerning the map content, in which reasoning participates, including also processes such as generalization, identification of regularity and explanation of the phenomena presented on maps (A. Czerny 1994). If a user does not have relevant knowledge and the map does not apply logical association, the information is rejected as insignificant or new information is saved in the memory.

According to E. Nęcka et al. (2013) two basic types of reasoning are applied in thinking: deductive and inductive. Deductive reasoning involves making conclusions based on prerequisites from the image, using principles of logic and possessed geographical knowledge.

[4] Problems related to perceiving and distinguishing signs were discussed in the article about features of a cartographic image in map perception (W. Żyszkowska 2016).

An area of heavy rain on a map may suggest e.g. that there is a mountain range. Inductive reasoning involves introduction of hypotheses based on regularity of occurrence and co-occurrence of phenomena. Particular phenomena constitute prerequisites here, and their prevalence leads to conclusions. Looking at e.g. a soil map, we notice that alluvial soils occur in river valleys. Such reasoning is used also in the analysis of correlations between phenomena, e.g. impact of valleys and mountain ridges on distribution of people as well as forecasting certain phenomena based on synoptic maps.

Apart from factors related to perception, in map interpretation semantic and psychological aspects play an important role (A. Makowski 1967, J.C. Patton and T.A. Slocum 1985). Using semantic relations of visual variables with the presented phenomena is based on the isomorphism principle which concerns mainly the shapes of signs and various attributes of colors; however, it is important that both intended and unintended relations operate here. Intended relations use commonly known impressions related to particular colors: red – warm, blue – cold, water, green – plants, etc. Unintended impressions concern e.g. hypsometric colors recognized as elements or features of the environment on the presented area, such as dry regions or vegetation.

2.3.3. Memory of spatial distribution. Mental map

Identification of objects of geographical space on the map and interpretation of its content constitute the basis to introduce information into memory structures. The map contains a specific type of information, as it is both an image and a language code. Therefore, in the process of map perception elements of visual perception interact with elements of language perception. In the brain, a resource of information called geographical knowledge or spatial representation is created, which may have a double nature: verbal or pictorial (I. Kurcz 1987, A. Nowak 1991, W. Żyszkowska 1999).

Spatial information kept in the long-term memory integrates information from various sources and creates a thinking structure defined as spatial representation or a mental map. Its fundamental components are spatial frameworks in which incoming information is placed subsequently. Properties of such frameworks and elements of mental maps affect the nature of geographical knowledge of the recipient (W. Żyszkowska 1996).

Due to striving to maximally reduce the amount of information coming into the brain which is typical for the brain, an important feature of mental maps is organization of special information into hierarchy structures, e.g. grouping towns into regions (R. Eastman 1985) as well as deformation of spatial relations between particular elements and their groups. It is a phenomenon independent of consciousness and it causes various deformations: grouping and positioning of objects in one line, their rotation and overestimation of distances to places nearby and underestimation of distances to distant places. Moreover, frameworks for particular places do not create a consistent entirety similar to a map, but their particular fragments may function separately, and the relations concerning a certain group of objects do not have to be connected into a whole with the remaining content of the map and the possessed knowledge (W. Żyszkowska 1996, R.E. Lloyd and D. Patton 2011). However, such properties are also conditioned by the experience and knowledge of the recipient of a map and the level of engagement of their attention (M.W. Dobson 1985, B. Tversky 1992, W. Żyszkowska 1996).

3. Factors affecting map perception

Due to the complexity of the process of map perception, it is affected by several factors. It varies depending on the nature of a map, cartographic competences and the degree of intellectual involvement of the user of a map, tasks resulting from the map function as well as the nature of the information obtained. In recent years, an increasing role has been played by differentiation of map carriers and situations in which a given map is perceived.

3.1. Nature of a map

The fundamental factor of efficient map perception is its structure compliant with cartographic principles, to which recently – particularly in the context of universality of maps in the press and the Internet – more attention should be paid (J. Korycka-Skorupa 2015). A. Robin-

son et al. (1978) believe the following properties to be the most important features of maps: transparency, legibility, contrast and visual balance. Transparency and legibility depend on the degree of complexity which concerns both the content and the map graphic form (W. Żyszkowska 1993, A. Ciołkosz-Styk 2011). Also, presentation of terms and attributes using signs built in accordance with cartographic principles (W. Żyszkowska et al. 2012), which is related to map logic (J. Pravda 2004) should be added. The legend must be clear and legible, however various layouts and structures of the legend are acceptable (I. Gołębiowska 2011).

Map perception depends also on its scale and content, to which the nature of the used cartographic language is adjusted. We perceive topographic maps in a different manner than general maps, and various thematic maps also in a different manner. Their content affects the type of tasks that can be implemented using them, and as a consequence the nature of the information obtained.

3.2. Features of recipients – cartographic competences

The ability of the user to look at a map is determined by the condition of sight of the recipient which decides about the nature of perception. People with severe sight defects use touch perception with a completely different nature which is subject to different rights and must be treated separately. The second condition to understand a map is compatibility of the author and the user of the map concerning the terms meaning phenomena presented on a given map (J. Keates 1982), which may be determined as cartographic competencies. They depend on the age and education of the map user and they are shaped at various educational levels and during travelling. The user should have basic knowledge about the map and the phenomena presented on it, knowledge to understand what it presented on the map and assign meaning to abstract signs as well as understand differences between signs as differences between features of phenomena. The map user who does not have such knowledge must receive relevant instructions concerning the content of the map and its interpretation.

3.3. Tasks related to map perception

The manner of using a map depends on the nature of information we wish to obtain, and therefore the purpose of map use. There are many tasks for which maps are used as tools, but obtaining information, orientation and navigation as well as interpretation of phenomena occurring in the geographical space have fundamental significance resulting from the function of maps.

3.3.1. Collecting information

The simplest perception tasks are operations related to collecting information about the location of objects. They involve identification of signs – perceiving, differentiating them from other signs and assigning a specified meaning to them. Attention is also involved here and depending on the type of the task – long-term memory.

A more complex task involves finding objects which belong to a determined class marked in the legend. The user must introduce a sign from the legend meaning the type of objects into visual memory, and then in the process of a cognitively guided visual search, compare signs perceived on the map with the signs in the legend. If they are not compliant with them, they are removed from memory. In the case of identifying more signs, it is necessary to transfer information about signs into long-term memory. A significant role is played by isomorphism of signs which facilitates connecting signs with their meanings (L. Ratajski 1971, P. Grohman 1975).

3.3.2. Orientation and navigation

Since the beginning of the existence of maps, their fundamental functions are orientation and navigation[5]. These tasks are strictly related to one another; however, their cognitive processes have a different nature. Orientation may be the purpose in itself, and therefore it is the first stage of navigation. Currently, programs and devices for orientation and navigation are used frequently, however certainly for some

[5] The term “navigation” is used here to determine activities related to movement in space, including walking or driving vehicles, and not only on water or in relations to sailing.

time maps will be the most basic tool to implement such tasks.

We deal with orientation, i.e. determination of our own location using a map, in two cases: when we wish to identify our location in the field on a map and when we wish to find a place where we are in the field on a map. In both cases, the task involves assessment of topological relations in the horizontal perspective and its transformation into the vertical perspective of a map and vice versus. Perceiving signs requires greater participation of visual search, and perceiving spatial relations, i.e. distance and directions as well as the potential type of neighborhood, requires more intensive engagement of attention, memory and reasoning.

Navigation, i.e. determining a route involves selection of one of several routes between two places. The basis for this action is orientation, however two elements of the location are additionally determined – distance and direction. When determining distance, it is necessary to take the map scale into account. Apart from this, memorizing not one, but several points with their spatial relations and sequence comes into play, and then comparison of several possible connection and memorization of the selected version. The task is related to a highly selective process of visual search which each time is guided by the user's assessment. A specific type of thinking processes participates in navigation, i.e. creation of alternative hypotheses about the optimal route and their verification as well as forecasting a future action and making a decision.

3.3.3. Map interpretation

Map interpretation leads to the knowledge about space, i.e. spatial representation. Determining spatial dependencies presented on a map of phenomena is a very complex task. Such tasks vary depending on the type of phenomena, the nature of its distribution and on the manner of presenting them on a given map. A point distribution is described differently than a linear or space distribution. Different thinking processes are involved in identification of distribution on a general map and different in the case of thematic maps presenting various phenomena and applying different levels of presenting information and visual variables.

3.4. The nature of information possible to obtain from a map

The fundamental type of information which can be obtained from a map, regardless of the scope of its content and the manner of presentation, is information related to the occurrence and location of objects in space, which B.B. Petchenik (1979) determined as "here it is" type of knowledge. It refers to the location and spatial references of particular objects and it constitutes significant content of all maps. It also has a nature of semantic information and to read it, it is necessary to know terms which constitute elements of knowledge of the map user and are included in the legend of a given map, as well as knowledge of semantic principles governing them (A. Czerny 1994).

Such information constitutes the basis to shape the second type of information which according to B.B. Petchenik creates "I know about space" type of experienced knowledge. It consists of various types of relations between particular objects or areas on a given map. It has a structural nature and it can be obtained by inductive or deductive reasoning based on prerequisites contained in spatial relations, such as coexistence, neighborhoods, etc. or cartometric measurements (A. Czerny 1994).

Knowledge about space includes a broad scope of matters. Apart from location, it concerns various aspects, spatial dimensions of objects creating it, distributed in various manners and forming different relations with one another, being in various dynamic situations, characterized by different attributes included at various levels of abstraction (W. Żyszkowska et al. 2012).

Understanding relations between elements of a given map can take place at the regional level, when neighborhood and coexistence are determined, or at the general level, where the general space patterns is determined. It may include qualitative features, when their distribution is characterized, or quantitative features, when diversity of object dimensions or phenomena intensity is characterized. Comparing maps from different periods leads to a conclusion concerning changes in time. It is obvious that the broader the geographical knowledge of the map user, the broader the scope of relations he/she can perceive, the more effectively and deeply he/she can interpret the pheno-

mena presented on the map and their spatial relations.

3.5. Process of map perception

The manner of map perception also depends on the environment in which maps function. Traditional maps, printed on sheets of paper, are replaced by maps displayed on computer monitor screens with increasing frequency. Their diversity causes a need to separately treat this subject and recently they have become a subject of studies also in the scope of map perception (X. Li, Çöltekin and M.-J. Kraak 2010; A. Çöltekin, S.I. Fabrikant and M. Lacayo 2010; T. Opach 2011). The fundamental difference in the perception of both types of maps involves stability of traditional maps and the possibility to introduce changes in the case of computer maps. Such changes involve most of all the possibility to freely zoom in and zoom out on the map and its spatial reach as well as the possibility to quickly go from one image to another. It is also important that as opposed to traditional maps, in computer systems information is saved in databases and it can be additional displayed on a screen when looking at a given map. However, knowledge of the general spatial distribution is only possible through maps.

New possibilities for developing maps in the new environment also change the manner in which maps are perceived. In traditional cartography, the size of signs was adjusted to the standard distance of approx. 30 cm, from which people look at traditional maps. Maps which were viewed from a larger distance must have had larger symbols. In the case of computer maps, it is possible to adjust the size of the image to the needs of the viewer; however, it occurs at the expense of reducing the range of the area that can be seen. The traditional situation involves viewing a map placed on a well-lit table; however traditional maps were also used in extreme situations and stressful situations – during sports competitions or wars, when time is a factor deciding about implementation of a given task, and movement and changing conditions of lighting additionally impede identification of signs on the map. Similar conditions occur in the case of navigation systems and improvement of map perception functioning in them constitutes an important task of modern cartography.

4. Conclusions

In the last twenty years of the previous century numerous studies were conducted to clarify various aspects of the process of perception regarding traditional maps printed on paper and viewed mostly on tables. Today, the dominating manner of using maps is their perception on monitors, including navigation systems, knowledge of factors conditioning it is still significant for the understanding of this process. The basic process participating in cartographic information processing at various levels and stages of perception is a visual search, which recently constitutes a subject of studies using the latest research eye tracking tools. Matters related to other processes constituting map perception and factors affecting its nature currently attract less attention. Identification of objects and interpretation of information lead to the occurrence of spatial representations in the form of mental maps which constitute the fundamental component of our spatial knowledge. In the analysis of map perception, also tasks implemented using maps and the nature of information obtained by the map used must be considered. The review of matters concerning map perception conducted in this article may indicate a perspective for further directions of studies on the process.

Literature

Anderson J.R., 1995, *Cognitive psychology and its implication*. New York: Freeman, 519 pp.

Arnheim R., 1976, *The perception of maps*. "The American Cartographer" Vol. 3, no. 1, pp. 5–10.

Bertin J., 1967, *Semiologie graphique*. *Les diagrammes, les reseaux, les cartes*. Paris: Mouton/Gauthier-Villars, 431 pp.

Castner H.W., Lywood D.W., 1978, *Eye movement recording. Some approaches to the study of map perception*. "The Canadian Cartographer" Vol. 15, no. 2, pp. 142–150.

Cave K.R., Wolfe J.M., 1990, *Modeling the role of parallel processing in visual search*. "Cognitive Psychology" Vol. 22, pp. 225–271.

Ciołkosz-Styk A., 2011, *Analiza treści i ocena efektywności europejskich planów miast*. Doctor dissertation, Uniwersytet Warszawski.

Çöltekin A., Fabrikant S.I., Lacayo M., 2010*, Exploring the efficiency of users' visual analytics strategies based on sequence analysis of eye movement recordings*. „Intern. Journal of Geographical Information Science" Vol. 24, no. 10, pp. 1559–1575.

Çöltekin A., Kraak M.-J., 2010, *Visual exploratin of eye-movement data using the space-time-cube*. In: Geographic Information Science, 6th International Conference GIScience 2010, Zurich, Switzerland, September 14–17, 2010. Proceedings. Berlin: Springer, pp. 295–309.

Czerny A., 1994, *Cartographic model of reality. Structures and properties*. „Geographical Studies" Polish Academy of Sciences, Special Issue No. 7, Wrocław: Ossolineum.

De Lucia A.A., 1976, *How people read maps: some objective evidence*. In: Proceedings of ACSM 36 Annual Meeting, pp.135–144.

Dobson M.W., 1977, *Eye movement parameters and map reading*. "The American Cartographer" Vol. 4, no. 1, pp. 39–58.

Dobson M.W., 1979, *The influence of map information on fixation localization*. "The American Cartographer" Vol. 6, no. 1, pp. 51–65.

Dobson M.W., 1985, *The future of perceptual cartography*. "Cartographica" Vol. 22, no. 2, pp. 27–43.

Eastman J.R., 1985, *Graphic organization and memory structures for map learning*. "Cartographica" Vol. 2, no. 21, pp. 1–20.

Gołębiowska I., 2011, *Zastosowanie protokołów głośnego myślenia w badaniach kartograficznych*. „Polski Przegląd Kartograficzny" T. 43, nr 4, pp. 341–353.

Grohman P., 1975*, Alters und Geschlechtspezifische Unterschiede in Einpragen und wiedererkennen Kartographischer Figurensignaturen.* „Forschungen zur theoretischen Kartographie. Veröffentlichungen des Institutes für Kartographie Österreichischen Akademie der Wissenschaften" Bd. 2, Wien, 74 pp.

Head C.G., 1984, *The map as natural language: a paradigm for understanding*. "Cartographica" Vol. 21, no. 1, pp. 1–32.

Jenks G.F., 1973, *Visual integration in thematic mapping. Fact or fiction?* „Internat. Jahrbuch für Kartographie" Jg. 13, pp. 27–35.

Keates J.S., 1982, *Understanding maps.* London: Longman.

Korycka-Skorupa J., 2015, *Efektywność metod prezentacji stosowanych na mapach tematycznych w prasie i Internecie*. „Polski Przegląd Kartograficzny" T. 47, nr 1, pp. 7–20.

Kurcz I., 1987, *Język a reprezentacja świata w umyśle*. Warszawa: PWN.

Li X., Çöltekin A., Kraak M.-J., 2010, *Visual exploration of eye movement data using the space-time-cub*. "Lecture Notes in Computer Science" Vol. 6292, pp. 295–309, Berlin: Springer.

Lloyd R.E., Patton D., 2011, *Maps and biased familiarity: Cognitive distance error and reference points*. "Cartographica" Vol. 46, no. 3, pp. 170–184.

MacEachren A.M., 1995, *How maps work: Representation, visualization and design*. New York: Guilford.

Makowski A., 1967, *Aesthetic and utilitarian aspects of colour in cartography*. „Intern. Jahrbuch für Kartographie" Jg. 7, pp. 62–87.

Materska M., Tyszka T. (eds.), 1997, *Psychologia i poznanie*. Warszawa: Wydawnictwo Naukowe PWN, 310 pp.

Montello D.R., 2002, *Cognitive map-design research in twentieth century: theoretical and empirical approaches.* "Cartography and Geogr. Information Science" Vol. 29, no. 3, pp. 283–304.

Nęcka E., Orzechowski J., Szymura B., 2013, *Psychologia poznawcza*. Warszawa: Wydawnictwo Naukowe PWN, SWPS.

Nowak A., 1991, *Wyobrażeniowe mechanizmy przetwarzania informacji*. Wrocław: Ossolineum.

Olson J.M., 1976, *A coordinated approach to map communication improvement*. "The American Cartographer" Vol. 3, no. 2, pp. 151–159.

Opach T., 2011, *Zastosowanie okulografii w kartografii*. „Polski Przegląd Kartograficzny" T. 43, nr 2, pp. 155–169.

Patton J.C., Slocum T.A., 1985, *Spatial pattern recall. An analysis of the aesthetic use of colour*. "Cartographica" Vol. 22, no. 3, pp. 70–87.

Petchenik B.B., 1979, *From place to space: the psychological achievement of thematic mapping*. "The American Cartographer" Vol. 6, no. 1, pp. 5–12.

Pravda J., 2004, *Nekol'ko poznamok o logike mapy*. „Geograficky časopis" R. 56, nr 3, pp. 249–261.

Ratajski L., 1971, *Zasady logiczno-semiotyczne uporządkowania i standaryzacji znaków kartograficznych*. „Polski Przegląd Kartograficzny" T. 3, nr 3, pp. 106–116; nr 4, pp. 156–166.

Ratajski L., 1978, *Główne cechy przekazu kartograficznego jako część kartografii teoretycznej*. „Polski Przegląd Kartograficzny" T. 10, nr 3, pp. 113–125.

Ratajski L., 1989, *Metodyka kartografii społeczno-gospodarczej*. Warszawa: PPWK.

Robinson A.H., Sale R.D., Morrison J.L., 1978, *Elements of Cartography*. New York: Wiley.

Robinson A.H., Petchenik B.B., 1976, *The Nature of Maps: Essays toward Understanding Maps and Mapping*. Chicago: University of Chicago Press.

Sandford H.A., 1980, *Directed and free search of the school atlas map*. "The Cartogr. Journal" Vol.17, no. 2, pp. 83–92.

Tversky B., 1992, *Distortion in cognitive maps*. "Geoforum" Vol. 23, no. 2, pp. 131–138.

Żyszkowska W., 1993, *Złożoność jako właściwość obrazu kartograficznego i jej wpływ na odbiór mapy*. „Polski Przegląd Kartograficzny" T. 25, nr 3, pp. 116–125.

Żyszkowska W., 1996, *Mapy mentalne Polski uczniów klas licealnych*. „Polski Przegląd Kartograficzny" T. 27, nr 1, pp. 9–29.

Żyszkowska W., 1999, *Cognitive aspects of map perception and factors causing differences between individuals*. "The Polish Cartography" Warszawa: Head Office of Geodesy and Cartography, pp. 72–82.

Żyszkowska W., Spallek W., Borowicz D., 2012, *Kartografia tematyczna*. Warszawa: Wydawnictwo Naukowe PWN.

Żyszkowska W., 2015, *Map perception: theories and research in the second half of the twentieth century*. "Polish Cartographical Review" Vol. 47, no. 4, pp. 179−190. DOI: 10.1515/pcr-2015-0017.

Żyszkowska W., 2016, *Visual features of cartographic representation in map perception*. „Polish Cartographical Review" Vol. 48, no. 1, pp. 5−15. DOI: 10.1515/pcr-2016-0003.